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Published in:
Powder Technology

DOI:
10.1016/s0032-5910(97)03278-6

ELSEVIER

Powder Technology 93 (1997) 185–188

POWDER TECHNOLOGY

Letter

The influence of perforated baffles on the mixing and segregation of a binary group B mixture in a gas–solid fluidized bed

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Received 11 June 1996; revised 7 April 1997; accepted 27 May 1997

Abstract

This paper presents a method of influencing the axial mixing of particles and promoting segregation in fluidized beds without otherwise changing the character of the bed substantially (at least at low to moderate gas velocities). The method is based on the introduction in the bed of horizontal screen-like baffles with a relatively large free area. It will be shown that such baffles promote the particle segregation significantly, producing a layer of almost pure heavy/large particles in a binary mixture which would be well mixed when fluidized in a conventional bed at the same velocity. The effect of three different types of baffles, of the number of baffles and of the fluidization velocity on the quality of separation is examined. A physical reason for the demixing effect is suggested.

Keywords: Fluidized beds; Baffles; Segregation; Mixing; Classification

1. Introduction

The degree of axial mixing of particles in fluidized beds is important for many continuous or batch processes, and control thereof is desirable. In fluidized beds consisting of particles with different size and/or density a concentration profile will develop over the height of the bed at moderate gas velocities. For applications of fluidized beds such as coating, granulation, drying and catalyst regeneration it would be advantageous if separation, based on differences in the physical properties of the 'reactant' and 'product' particles, could be achieved, and to some extent controlled, making improved product quality attainable and continuous processing possible. Dry separation of particles on the basis of differences in density is also interesting in other contexts, such as in the recycling industry (e.g. separation of different plastics).

The influence of internal baffles on the behaviour of fluidized beds has been reviewed by Harrison and Grace [1] and Sitnai and Whitehead [2] for reactor design purposes. In uniform solids it has been observed that internal baffles restrict large-scale solids movement. Bubble splitting was observed at the high gas velocities used. In continuous fluidized beds consisting of uniform particles, horizontal perforated baffles have been used to subdivide the bed in stages, thus narrowing the residence time distribution of both gas and solids in continuous beds consisting of uniform particles [3]. Gelperin et al. [4] investigated the classification of a binary mixture of coal particles in a conical baffled fluidized bed. Using perforated plates (openings 3 mm in diameter, 10 mm apart) and high gas velocities they were able to preferably carry over the fines at the top of the bed. Zhang and Beeckmans [5] showed that mechanically stirring a fluidized bed suppresses the bubbles and reduces the axial mixing of particles. In a three-component system, using a virtually bubble-free fluidizing medium with bulk density between jetsam and flotsam particles, continuous separation of solids was possible using rod stirrers [6] and improved by using screen-like stirrers [7]. However, without a fluidizing medium (a two-component system containing only particles to be separated) the separation was inferior to an ordinary fluidized bed, probably due to the destruction of the pure jetsam layer at the bottom of the bed.

It is shown in this article that a binary mixture can be effectively demixed in a batch bed using stationary horizontal screen-like baffles with a relatively large free area [1]. The introduction of the baffles did not significantly alter the bubble characteristics (at least at low to moderate gas velocities) and the bed remained a single-stage fluidized bed. The effect of three different types of baffles, of the number of baffles and of the fluidization velocity on the quality of separation

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[1] Patent application has been filed.

0032-5910/97/$17.00
PII S0032-5910(97)03278-6

has been examined. A mechanism is proposed which explains why the baffles have a small effect on the bubble behaviour but a large effect on the mixing. No attempt has, at this point, been made to optimize the process in a systematic manner.

2. Experimental

Both an 8.7 cm and a 14.7 cm i.d. glass column with porous distributors made from sintered glass were used (the results obtained in the latter will be presented in another context). In order to ensure constant fluidization conditions [8] the relative humidity of the fluidizing air was kept at a constant value of 45% by means of a humidification unit. Fig. 1 shows the geometry of the perforated baffles used and characteristics are given in Table 1. The baffle module used in the experiments was constructed with three threaded tie-rods, 2.4 mm thick, positioned near the edge of the baffle at angular intervals of 120°. The construction is illustrated in Fig. 1. The baffles were not rotated relative to each other and the distance between them was set with tubes of length 1.5 cm acting as spacers. Baffles and spacers were held in place by means of screws at each end.

Experiments were performed using an equal-density binary mixture consisting of 750 g of glass ballotini with a surface mean diameter of 559 μm and 750 g glass ballotini with a surface mean diameter of 268 μm. The particle density was 2500 kg/m^3. The minimum fluidization velocities of the two fractions are 0.23 m/s and 0.072 m/s, respectively. Mixing experiments were performed at superficial gas velocities of 0.178, 0.208 and 0.249 m/s. At the last two gas velocities the mixture was allowed to mix well without baffles present,

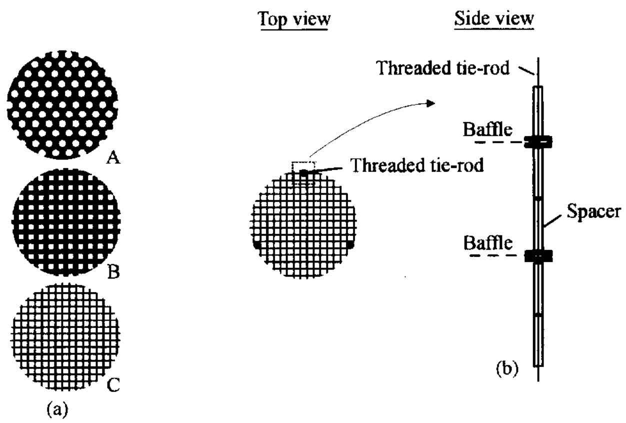

Fig. 1. (a) Perforated baffle types and (b) baffle module construction used.

Table 1
Characteristics of the baffles

Type of baffle (Fig. 1)	Thickness of baffle in axial direction (mm)	Diameter or side length of holes (mm)	Fractional closed area
A	3.15	7.0	0.70
B	2.50	5.0	0.56
C	0.75	3.3	0.34

whereafter the baffle module was introduced into the bed and the system was allowed to reach a steady state. The gas was then shut off and the bed was sectioned in layers with a vacuum technique. When uncovered, each baffle could be removed individually from the bed, without disturbing it, by undoing the screws at the top of the module. The concentrations of the components in each layer were determined by sieving. At the lowest gas velocity of 0.178 m/s and without baffles a segregated layer (containing a high concentration of flotsam) already existed in the bed. This made it necessary to use a special experimental procedure. Rather than mixing the bed first and then inserting the baffle module a well-mixed state was achieved with the baffle module already in the bed using extremely high fluidization velocities. The gas velocity was then decreased to the desired value of 0.178 m/s, whereafter the procedure described above was used to analyse the bed.

3. Results

Introducing the baffle module in the bubbling fluidized bed did not visibly disturb the bubble behaviour (coalescence or rise velocity), at least at the moderate gas velocities used in the mixing experiments. Sometimes a small, non-stationary, powder-free section was observed underneath a baffle with bubble splitting above it. At much higher gas velocities than the ones used in the study, the baffles did disturb the bed, stationary powder-free sections were observed under each baffle and smaller bubbles were formed above them. At these high velocities smaller bubbles were also observed on the bed surface. These observations are consistent with observations of Jun et al. [3] on the solids backmixing between stages in a baffled multistage gas-fluidized bed, and with the results of Kunii and Levenspiel [9], Winter et al. [10] and Hilligardt and Werther [11] showing that, at high fluidization velocities, horizontal baffles and heat exchanging tubes cause a reduction in the mean bubble size.

The observation that the baffles did not influence the bubble behaviour appreciably at the moderate gas velocities of this study was confirmed by bed height measurements in the 8.7 cm i.d. bed. The bubble hold-up (defined as the fraction of the total bed volume taken up by bubble voids) in single-component beds, fluidized without baffles and with an optimum baffle configuration (five type C baffles, see below), is shown as a function of the excess gas velocity in Fig. 2. It is

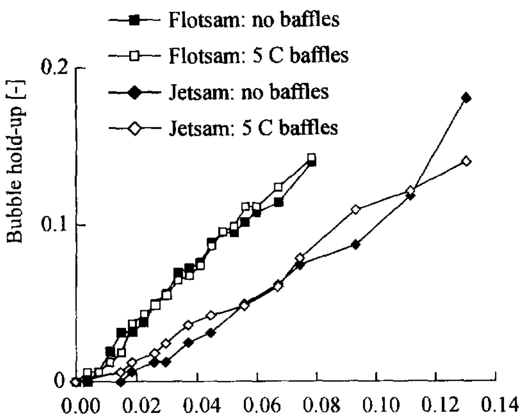

Fig. 2. Bubble hold-up as a function of the excess gas velocity for 1500 g beds containing pure flotsam (268 μm) and jetsam (559 μm), respectively (8.7 cm i.d.).

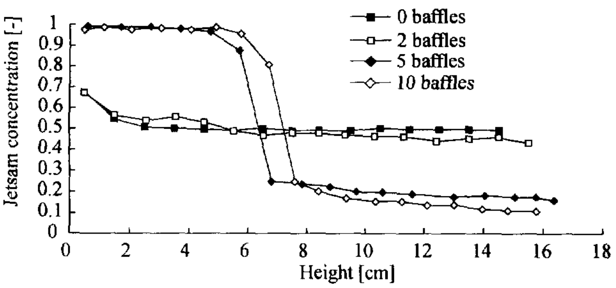

Fig. 3. Influence of the number of type B baffles in the bed on the concentration profile (superficial gas velocity 0.208 m/s, 8.7 cm i.d.).

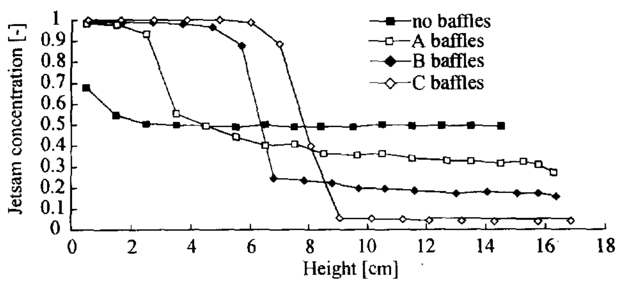

Fig. 4. Influence of the type of perforated baffles in the bed on the concentration profile (five baffles used, superficial gas velocity 0.208 m/s, 8.7 cm i.d.).

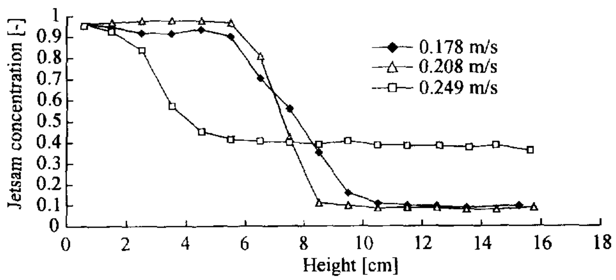

Fig. 5. Influence of the superficial gas velocity on the concentration profile for type C baffles (8.7 cm i.d.).

clear that the presence of the baffles does not influence the bubble behaviour significantly.

In spite of the bubbles thus appearing largely undisturbed by the presence of the baffles, a segregated layer started forming at the bottom of the bed after introducing the baffles and it was evident that the effect of the baffles was to promote demixing. Fig. 3 shows the effect of the baffles and the influence of the number of type B baffles on the steady-state concentration profile in the 8.7 cm i.d. bed. In these experiments it was observed that the time needed to reach a steady state (where the height of the segregated layer no longer increased) increased by introducing baffles in the bed. This aspect will be investigated further. The effect of the baffles in promoting demixing is very significant, as shown by the formation of a bottom layer with high jetsam concentration and a top layer with low jetsam concentration. The formation of two layers each of constant composition is typical for segregated beds. It can be seen that demixing is almost complete with five or ten baffles present, although the bed can be seen to be well mixed without baffles at the fluidization velocity used. Fig. 4 shows the effect of different baffle geometries, and Fig. 5 shows the influence of the gas velocity on the concentration profile in a bed with five type C baffles. In these experiments the particle properties had changed slightly due to cleaning of their surface, made necessary by the accumulation of contaminants on them. After ultrasonic cleaning they appeared to be slightly more cohesive. In the segregated layer, very tiny bubbles were observed at the gas velocity of 0.208 m/s, which enhanced the demixing. At 0.178 m/s no bubbles were observed in the segregated layer and at 0.249 m/s large bubbles were seen to rise through the segregated layer.

Mixing experiments in the 14.7 cm i.d. column showed the same demixing efficiency of the baffles. However, the concentration of jetsam in the top increased by about 0.05. This is probably the result of the larger rise velocity of the bubbles in the 14.7 cm i.d. bed compared with the 8.7 cm i.d. bed.

Exploratory qualitative studies showed that the baffle module also demixed a different density mixture consisting of 559 μm glass ballotini and a bronze powder of mean diameter 273 μm and particle density 8650 kg/m^3 in accordance with the difference in density, in spite of the opposite driving force provided by the size difference. A segregating effect was even observed in a monosized (particle diameter around 500 μm) mixture of polypropylene and polyamide having densities of around 903 and 1145 kg/m^3, respectively.

4. Discussion and conclusions

It is well known that the main mixing mechanism in bubbling fluidized beds is the upward transport of jetsam material in the wake of rising bubbles (also, particle drift due to the movement of fluidization bubbles causes mixing). It has been observed that bubble wakes impact on horizontal tubes [12]. A plausible explanation for the reduced mixing with baffles (Figs. 3–5) consistent with this is that the wakes of rising bubbles impact on the baffles and lose their wake particles, whereafter new wakes will form above the baffle. This decreases the upward particle transport in the bed. The baffles may also reduce drift. The other transport processes, in particular the segregation of individual jetsam particles caused by the stirring action of fluidization bubbles, are only likely to be slightly hindered by the baffles. Thus both mixing and segregation processes are hindered by the baffles, but the former the most. The result is that the bed demixes more slowly but also more completely. From Fig. 4 it can be seen that type C baffles have the strongest influence in promoting segregation, although they have the smallest fractional closed area. With a higher fractional closed area and thicker internals the mean concentration of flotsam in the upper layer increases, which is opposite to the intuitively expected trend. The effect of the hole diameter on the demixing (smaller holes reduce the concentration in the upper layer) agrees with the intuitively expected trend. The latter parameter is therefore probably the most important in determining the degree of demixing.

From Fig. 5 it can be concluded that demixing is nearly fully achieved at 0.208 m/s. At this fluidization velocity, tiny bubbles disturb the segregated layer, thereby causing further demixing than observed at 0.178 m/s. On the other hand, at 0.208 m/s the bubbles are not so large as to cause excessive disturbance. Further research aimed at determining the mechanism behind the effect of the baffles more precisely is underway.

Acknowledgements

The authors gratefully acknowledge the contribution of Professor Dr A.A.C.M. Beenackers to the initial phase of this work.

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